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Development of appropriate processing technology for fruit export by smallholder farmers

Technical assistance in the processing of products of Equator Products Ltd. in Kenya

report of research activities in 2008

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Abstract

The creation of a value added chain for agri-products in Kenya needs the introduction of processing with a high quality level, making the export possible to countries with high standard regulations, such as the European Union members. Equator Products with a site at Malindi and at Matu is producing dried African Bird Eye Chilies for the Dutch market. The Chilies are tray-dried by indirect heated air. It is a batch process with trays mounted in trolleys, placed in a former transport container. Heating is done by using solar energy, biomass or oil. At the new Malindi site only oil is used as a fuel at the start of the new operations. A biomass burner will be placed later.
Also other products, based on additional processes, such as vacuum frying, are under development. Assistance has been given in the set-up of these new processes, especially vacuum frying of fruit and vegetables, resulting in a pilot/production unit.
The development of the processes has been assisted by experiments, designs, calculations and operational advice.

Experiments have been carried out at the Malindi site in the beginning of September. At that moment the process units were under construction. Measurements showed the limitations of the present container dryer, especially in the heat exchange between the boiler water and the air. Operational criteria have been measured and calculated. Design optimalisation has been suggested and partly implemented, such as the use of open trays. The dryer handels about 2000 kg fresh Chilies per shift, with 2 shifts per day. The heat exchanger is limiting the drying capacity.

Decontamination of the Chilies may further improve the already high hygienic standards. The use of a steam generator at the beginning of the drying process can give rise to further improvement of the decontaination.

Content

1. Introduction

The culture of vegetables, fruits, spices and flowers in Kenya is growing at elevated grounds and near the coast.The export of the products is directed to the more wealthy regions, mostly western and middle east countries. Air freight of these perishable products is common. Transport by container over sea is cheaper and sustainable but takes several days to a week. Therefore processing is needed for preservation.

In the BO project for LNV the appropriate processing of agri-products has been developed in relation to the production by small holder farms. The main product in this project is the African Bird Eye Chili. This product is dried and can be an example for other products. The packed dried product can be shipped easily. The essential partner in Kenya is the newly started company Equator Products Ltd.(EP). EP is responsible for the training of the farmers to produce the Chilies, the creation of the infrastructure, the drying process, packaging and export with the necessary infrastructure. Also Voortman in Rijssen (NL) takes part in EP. Several other companies and research groups from WUR participate in the project with the aim to create an example of a business model for processing with small holder producers. Other activities in this project include assistance in Farmer Field School establishment, and Integrated Pest Mangement. Most small holders own a few acres, cultivate mostly 0,25 acre of ABE and are often starters with ABE. Related to this LNV project is also a WSSD project, and assistance of PUM advisors. The Dutch involvement is strongly visible by the substantial grants of the Dutch government, the Dutch technical assistance and the Dutch owners.

Strong aspect of this project is the control over the supply chain from seed up to the export of the dried products. Teaching the right cultivation methods to the small farm holders, using a good water irrigation plan and (integrated) pest management (IPM), will give a product with a low contamination (microbiological and chemical residues). The product can be traced in the whole supply chain in much better accordance to EC regulations for hygiene and chemical residues than most Chillies on the market. The idea of the chain can be copied to other products within the current network, but can also be rolled-out to new networks.
The quality of the indirect dried products is superior to the local sun dried products.
Using an integrated pest management the Maximum Residue Level (MRL) will be lower en better controlled than for other spices on the market.
Low processing costs and sustainable handling have to come together in this project. Therefore organic production and processing using solar energy will help to obtain these targets, giving fair and sustainable trade arguments.

In this report the drying of the Chilies is discussed, together with the possible application of solar energy and new possibilities for products and the related processing.

The company has been founded recently and experience in the technologies, logistics and project/operational management is limited in agri-processing. The processing methods suggested are easy to use therefore, needing also limited investment and are easy to copy.

Equator products has started a new site at Malindi near the coast in summer 2008. In this start-up phase technical assistance has been given during a 11 days visit between 25/8/08 and 5/9/08 and future developments have been discussed with the owners of Equator Products.

The dryer design with calculations as discussed in chapter 4 are based on the container dryer at the Malindi site and the experiments done during the visit. The more specific information about the visit to the Malindi site is given in chapter 8.

2. The project

In Kenya a well-developed export-oriented supply chain for fresh flowers and fresh vegetables have been established. The export is directed to the Western countries and the transport is by air. The developments in the fruit sector are less distinctive. Causes are the dispersed and small-scale production, not well organised intermediate trade channels with low quality transportation facilities, and limited processing capacity, although fruits form also a high value and perishable products. So far also financial institutions have been very reluctant to invest in the fruit sector. During a recently organised Fruit Investment Conference, it was observed that export market for (processed) fruits is promising. Both private and the public sector organisations expressed willingness to support further development of the sector.
However, currently there is a tendency amongst fruit (and vegetable) exporters away from sourcing produce from small holders towards production by either relatively large out-growers or under own management. This trend forms a serious threat to the important small-scale producers in Kenya. The potential of processed fruits vegetables is certainly promising and will provide an appropriate alternative market opportunity for small producers. However, the processing industry in Kenya is underdeveloped and small-scale producers need access to appropriate and professional processing technologies at export standards.

A number of research activities have been conducted to explore the options for the export-oriented fruit sector in Kenya, Activities had to be set-up from the beginning, because hardly any concrete research and implementation pilots in processing involving small-holder producers exists. With the use of processing for preservation and the creation of an added product value the supply chain will obtain better opportunities.

This project is relevant for LNV policy since the development of the fruit sector in East Africa will contribute to pro-poor growth, especially when the activities are focused on the inclusion of smallholder producers. The activities are in line with, and actually contribute to the ongoing activities of the WSSD public-private partnership activities for market access in the horticultural sector in East Africa. The work is in close agreement with the needed developments suggested by the local agricultural counseler Dick Bruinsma.

Objectives
The **goal** of the BO project 10-006-049 of LNV and WUR is to contribute to sustainable income generation for small-scale farmers in Kenya through the production and processing of fruits, spices and vegetables for the export market by using appropriate processing technologies.

The project has the following **purpose**:

- To conduct research on and adaptation of existing solar-energy systems for a range of fruits with high market potential
- To develop commercial pilot supply chains with a centrally-organized processing unit and groups of small-holder producers (Farmers Field Schools)
- To analyse and evaluate the pilot supply chains resulting in a plan for up-scaling
- To develop technical assistance and pilot Farmers Field Schools aiming at developing sustainable processed fruits and vegetables supply chains for small-holder producers.

This report is based on the technical assistance given for to the development of the central processing units and the related supply chains. The technical assistance had several aspects:
-advising in new developments for processing and product use
-drying experiments with Chilies
-analyses of the drying processes obeserved
-calculations on the processes and procedure description of some of the processes.

3. The supply chain with the processing activities

This project forms an example of a supply chain for export. The control of the chain is from seed to sea container by one company. Production is done by many farmers with small pieces of land. Many of these farmers are informal owners of the land. As such this supply chain is typical for Africa, but also for many regions in Asia. The idea of creating a private "cooperation" with many farmers with an infrastructure owned by the private company is also typical for these areas. The base for this system of contract producers with assistance in the infrastructure, including knowledge, fertilizers, seed and garanteed purchase of the production by a central processor, is often applied now-a-days. It's a modern mixture of the cooperations owned by the farmers, contract production and direct sourcing to retailers and processors, combined with the need for high standards in production and processing to obtain the agri-products according to the global quality regulations.
Especially for fresh and perishable products, such as milk or fruit, the logistics has to be well organised. Food processes are characterised by the need of a constant supply and quality, while qualities of sourced products are variable. The transport and storage of raw material of a proper quality, packaging, storage, quality control and distribution after the process are critical aspects of the supply chain Especially if continuous processes are used, the requirements are high. Batch processes are more flexible although labour demanding and giving more safety risks.

In Kenya the process with the related supply chain for the dried Chilies contains the following steps:

0) Production management
The proper variety with the seed and growth conditions, including integrated pest control/management (IPM), will determine the raw material and the final quality possible.

1) Harvesting
The Chilies have to be picked at the right moment with the right colour. Picking is done by hand. Damage to the tissue has to be minimised, when the stem is detached during the picking. The moment of harvesting forms a part of the planning of the processor.

2)
Storage at the farmer
After the picking, the farmer will store the Chilies temporary. Humid and high temperature environments has to be avoided, because metabolic reactions giving blackening and other deficients will increase. Also fungi growth will happen. Good ventilation at a cool place is necessary. Second best option is to keep the Chilies ventilated in the sun.

3)
Collection with selection, weighing and transport
The material is collected and transported by the processor. Control and administration for the tracing forms an important part. Because transport can take several hours, the conditions during transport are important and have to be controlled. Especially dry conditions with moderate temperatures are important.

4)
Input at the processing plant
The material can be stored at low temperature (4-7C) or put to the process directly for preprocessing, such as blanching, or drying. Input needs a grading process. After processing the quality has to be determined and grading can be a part of the chain again. Especially foreign material has to picked out. After the blanching it can be stored again.

5)
Processing
This step comprimises the preprocessing steps and the drying operation, but also the grading, packaging and storage with the administration.

6)
Transport
The packed chilies are transported by container via Mombasa. This transport can take several weeks. The quality after landing in the European Union is determining the product value.

The list above can be simplified to a structured summary of activities/stations for planning, drawings and HACCP reasons:

Supply chain steps for the Chilies processing

1 Collecting/transport
11 picking
12 storage at the farm
13 weighing bag at collection centre of the group
14 sampling and adminstration
15 transport (car/motor/coach)

2 Fresh chili preprocessing
21 arrival (car/motor)
22 unloading fresh chilies
23 storage fresh chilies (eventually)
24 cleaning trays
25 sieving/filling blue crate/weighing
26 filling trays with fixed weight: 5 to 8 kg
27 loading trolleys with trays
28 trolleys storage
29 administration arrival chilies/sampling

3 Drying
31 loading dryer with trolleys
32 drying
33 boiler for heating air
34 control drying (PC logger)
35 measurement of Aw of mixed sample at beginning of drying
36 measurement of Aw at end of drying
37 dried sample preparation

4 Dried product unloading
41 temporary storage trolleys with dried product
42 unloading trays from trolley
43 tray in crate through sieve
44 storing filled crates
45 administration/sampling

5 Grading station
51 unloading crate with dried chili
52 grading tables
53 loading crate
54 storing crates
55 weighing chili waste

6 Packaging station
61 unloading crate to belt with metal detector
62 loading bag while weighing
62 packing closing
63 storage end product (cooled)
64 storage packaging materials

7 Lab/utilities/maintenance
71 storage measuring items
72 preparing samples (electricity necessary)
73 weighing/measuring
74 storage machinery
75 tooling
76 cleaning hands facility
77 cloth personel cupboard
78 toilets
79 cleaning material storage (krächer, chemicals)

4. The drying operation

4.1 What is happening during the drying process?

Drying makes it possible to store an agri-product for a loger period, while most reactions in the agriproduct need water. It is also more easily to dose and to transport.

The removal of the water by air drying forms a transport proces from the material to the air, needing energy to evaporate the water in the material.
The process is dominated by the heat and the mass transfer, giving also a decontamination of bacteria and other infections, and determining the quality of the final product.

In the next part the process will be described theoretically.

Heat and mass transfer
Drying is a preservation method in which water is evaporated. Evaporation of water needs energy. For every kilogram of water you need about 2400 kJ for evaporation. To heat the kilogram of water from 25C to 100C you only need 75 x 4.2 kJ = 315 kJ. Evaporation will happen at the surface of the material and due to heat needed the temperature will decrease adiabatically, as will happen as we sweat at our skin.
During drying heat is transported from the air to the surface. Heat can also be put to the material by radiation, a microwave field or superheated steam for instance, but air is most often used as an intermediair. If the material is wet, the transport of heat to the surface and transfer of mass by the water vapour from the surface will be in equilibrium, giving a temperature of the surface, called the wet bulb temperature, if the air velocity is high enough to be turbulent and to give a small layer of stagnant air on the surface. This air layer is controlling the drying process in the beginning of the drying, giving a constant drying rate. This stagnant layer depends on the air turbulence and therefore on the speed. The layer thickness becomes almost constant at higher speeds. Air is needed to bring heat to the surface and to take away the vapour. Therefore the air speed is also very important, but if the air speed is high enough the always present stagnant thin air layer will determine the process. Water has to diffuse from the inner of the material to the surface. Normally after some time the surface becomes dryer and from that moment on the internal transport through the material will control the drying more and more. Because, If the air temperature and air velocity stay constant, while the evaporation at the surface is slowing down, the surface temperature will obtain more and more the air temperature. In figure 4.1 below this is defined as period II.

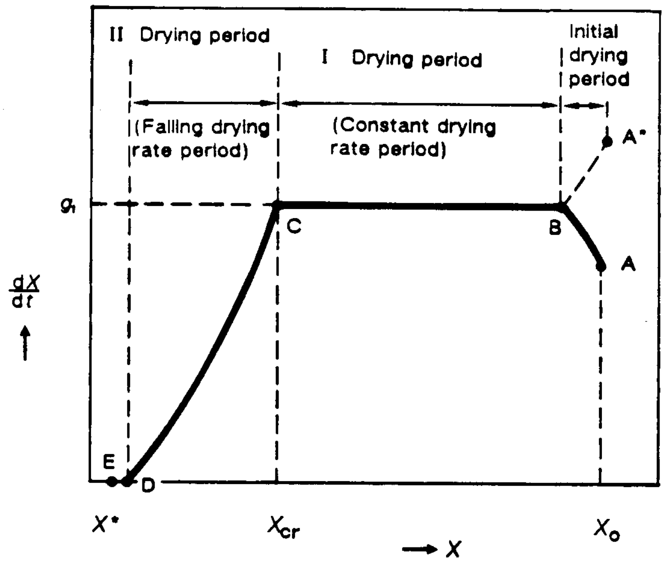


Figure 4.1 The drying process with the relative moisture content X at the x-axe and the drying speed as the decrease in time of this relative moisture content at the Y-axe. The process goes from right to left.

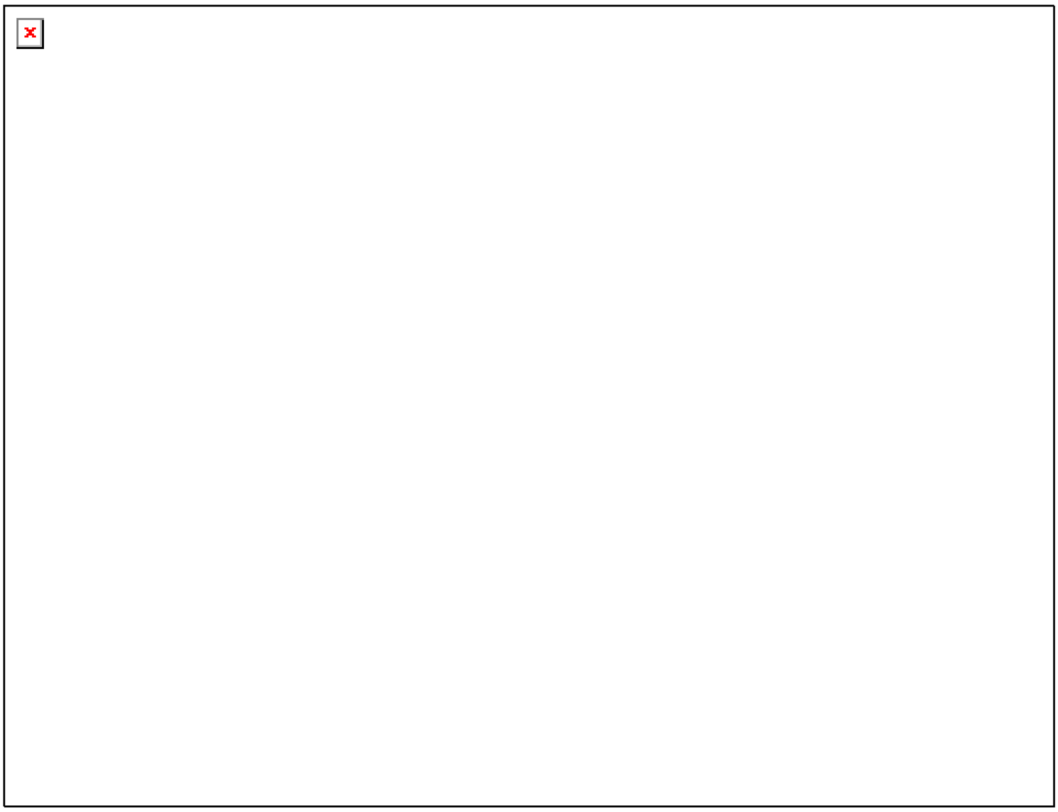


Figure 4.2 The drying process. See also the text above the figure.

In figure 4.2 the drying process is more traditionally presented, with the constant rate and falling rate periods given. The moisture content change is given by the line starting at the top of the moisture-axe (X) and the product temperature is given by the line starting at the top of the right side with the temperature-axe. Visible is that the product temperature stays constant in the constant (drying) rate period when the surface processes are controlling the drying.

The size of the material is determined by the air touched surface. In a fluid bed with the particles floating in the air, the size is related to the particle. In a bed of particles the controlling air layer is the bed surface and additional convective transport is possible through the pores in the bed, but the bed dimensions of the bed are then important.
Diffusion of the water in plant tissue is also obstructed by the active turgor of the plant cells, giving the cells the shape and strength. This internal pressure build up in the cell by the pump activity of the membrane is about 10 bar. If the temperature of the cells becomes higher then about 42ºC, enzymes are deactivated and the cell membrane will be passive, giving a higher internal diffusion rate. The wet bulb temperature is about 65ºC, so inactivation of the cell can be expected during the drying.

Decontamination
To obtain a high temperature of the plant material in the beginning of the process to kill micro organisms the evaporation of the water has to lowered. This is possible by using air with an relative humidity of 100%. By injecting steam in the air, the condensation will increase the temperature also rapidly. A temperature of 72ºC minimally during 15 s will pasteurise the material by decontamination of the vegative cells. To inactivate bacterial spores you need higher temperatures (180 s 121ºC). For spices often the McCormick process, comparable to the Stork steaming process, is used at 110 -140ºC, giving a 4log decontamination. Euroma in The Netherlands is using this process. Fungi spores are inactivated at lower temperatures than bacterial spores. Inactivation depends on the type of spore. For inactivation of the cell, an active metabolism is necessary and therefore humidity is essential. Dried bacteria are more difficult to inactivate.

Preservation because of drying is related to the need of water for metabolic processes of living cells. Drying gives an temporarely inactive material. After hydration cells can be active again if dried at the right conditions such as a low temperature. Also infections can remain inactive up to the moment of hydration. Also local condensation can give rise to growth in this way.

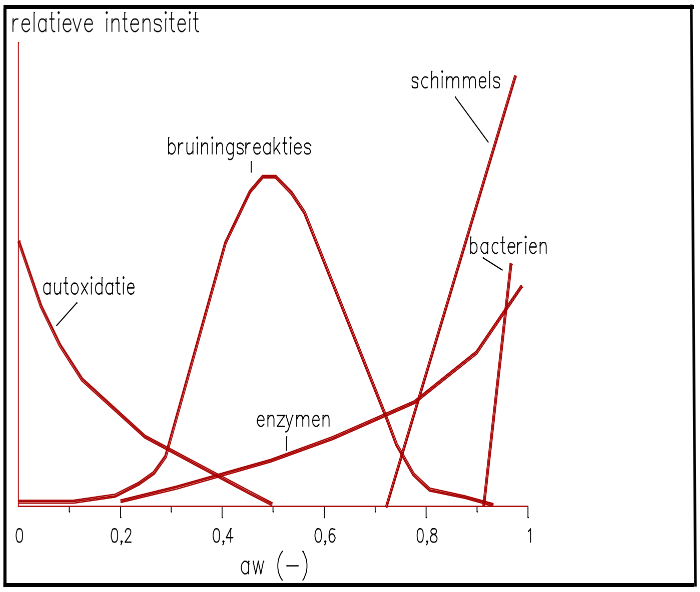


Figure 4.3 The growth rate of several reactions as a result of the water activity Aw (In Dutch: X-axe: Relative Intensity: relative intensity of reaction, Y-axe: Aw, auto-oxidation, browning reactions (Maillard), enzymes, fungi, bacteria)

In Figure 4.3 the reactions in the dried product are given. Especially the fungi (schimmels) and the enzymes are important for the Chilies. Auto-oxidation happens to fats especially and browning based on the Maillard reactions depends also on higher temperatures. For this reason a Aw of 0.6, or more safe of 0.55, is needed for the final product.

During the drying the right conditions for enzymatic reactions can occur. Polyphenoloxidase is known for the offcolouring after damage to the cell in the presence of oxygen. Also Katalase is an active enzyme, but not important for the Chili. Polyphenoloxidase (phenolase) is temperature resistent and still active at higher temperatures upto 70ºC.

Volatiles

At higher temperatures more etheric oils will evaporate, especially at temperatures above 50 ºC. Using steam will increase this extraction effect. Therefore the exhaust of the steam and air has to be minimized during the decontamination/pasteurisation step and during drying. The use of Zeolite with the specific water uptake will deminise the necessary spoil of air and therefore the losses on etheric oils.

4.2 The dryers

Dimensions
For the processing of the Chilies there are two 40 ft containers, being rebuild for the drying process.
The first dryer at Matu obtains the hot air from a roof that is used as a solar cell with additional heat from a burner. The second recently build dryer is now used at the site at Malindi, obtains the heat from a oil burner, creating hot water. This heat is brought to the circulating air by two air/water heat-exchangers (1460x1240x420 mm, bought via Peter van Dijk). The air loop with a spoilage also exists in Matu.
In the container two fans are mounted, each with 7.5 BHP. The fans use at 380 V about 11.0 A maximally, givings about 4 kW each gros. With 60% efficiency this gives 2.5 kW net to the air maximally. Both fans together will produce 5 kW net (=5000 J/s= 5000 Nm/s), necessary for $\Delta P \times V = \Delta P \times 10$ m3/s. So ΔP over the fans is maximally 500 Pa (= 0.005 bar, $\Delta P<0.01$ bar).

The dimensions of the 40 ft container are 11.6 mx2.33 mx2.45m gives a bottom surface of 67.5 m² with in total 95 m³ Volume. Normally a spoil of 20% of the air is used. At the malindi site the spoil is about 10%. The Malindi container has isolated walls. In every container fits 8 trolleys.

In Malindi a lift is necessary to bring the trolley into the container. Every trolley contains 38-40 trays at a distance of 5 cm (=2000 mm + 100 mm underneath). The trolleys do not have wheels. Every tray will be filled with 5 kg Chilies exact before the drying. This amount can increased to 7 kg at the Malindi site, while perforated trays are in use. The maximum capacity for fresh Chilies will be 8x40x5kg=1600 kg per shift and eventually 2240 kg per shift. It can be tried to put 8 kg on every tray in future, if necessary. With three shifts maximally per day and with 6 operational days per week the throughput can be optimised to 40000 kg fresh product per week in Malindi. Such an activity needs precise handling and logistics.

Tray design
Every tray at Malindi is for 33% perforated with 5 mm holes. The trays for the other location are closed aluminium plates. The boarder of the trays is 2.5 cm high, gives a free space for the slit between the trays of 2.5 cm for the air to pass. The trays are put into the trolleys from the side retangular to the air flow. Therefore the trolleys always have to be moved to collect trays, also inside the container. It will be easier to handle if the trays will be removed from the trolleys in the direction of the air flow. To obtain only the desired flow over the trays and between between the trolleys, coriginating from the lower pressure drop in this channels, flexible seals has to placed at the wall and roof sides of every trolley and the supposed non-flow sides of the trolleys have to been closed. This can be done with metal or plastic, but it should be easy to clean.

Optimisation of the tray design is an appropriate method to increase the dryer performance. A local upward flow can be created by mounting additional plates between the trays as shwn in the alternative design as given in figure 4.4. A simple system, giving a air flow through the bed of Chilies is possible by mounting small plates in the slit in flow direction between the trays can be closed, every second slit. At other side of tray the same type of plate is installed, but one slit upwards (or downwards). Result is that the air has to flow through the pores upwards or downwards. Velocities are of course lower than in the flow along the bed.

The new container dryer at Malindi:

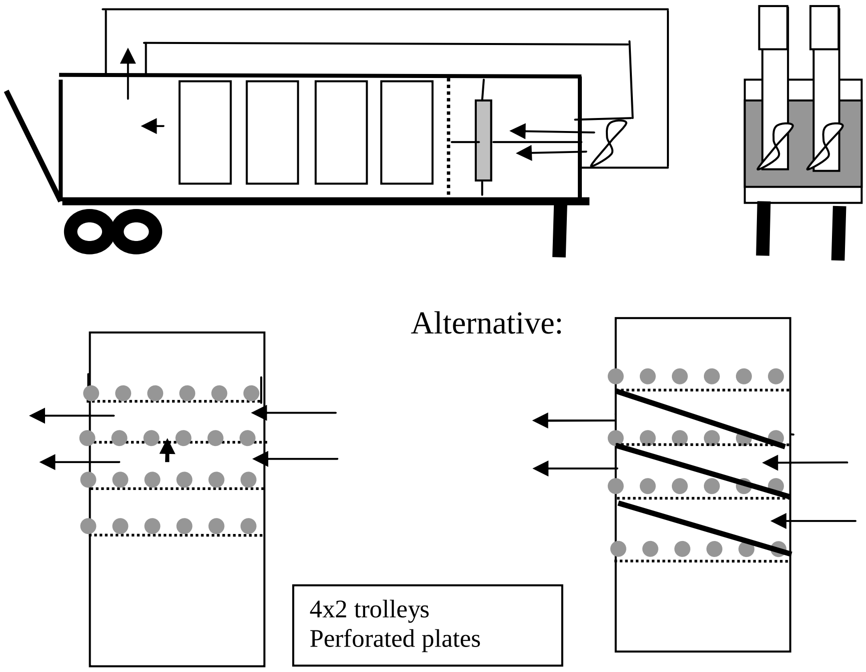


Figure 4.4 The container dryer with the schematic drawing of the trays in the trolleys. Two ways of the air flow are shown. The trays are perforated, giving some air flow through the bed of Chilies by local pressure differences.

Alternative process as used in reefers for circulating the air is showed below in figure 4.5. This flow can be created by shielding the sides of the trolleys, while creating more free space at the bottom. The loop can also be external as is the case now, but free space at the top is necessary.

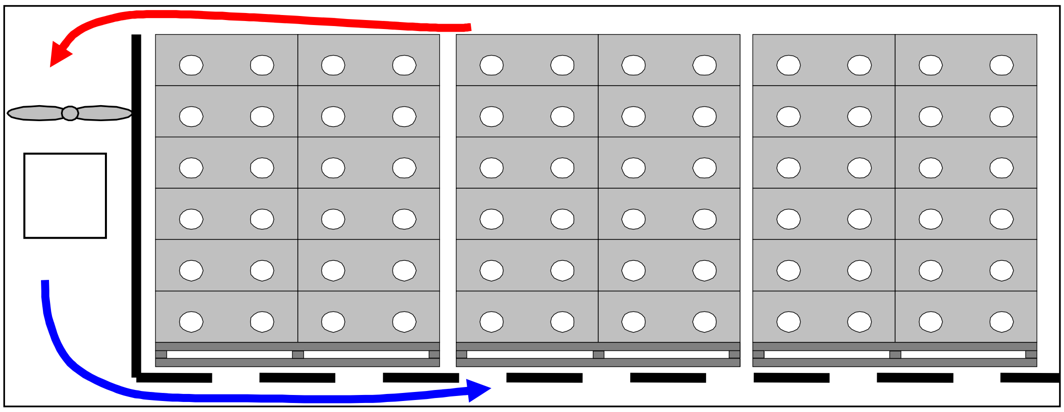


Figure 4.5 Flow through the boxes or trays as used normally in reefers

Some combination of both the alternative trays in figure 4.4 and the system in figure 4.5 is given in figure 4.6. The trays can also be obtained out of the "trolley" from the side, while the baffles stay in the frame (nor shown in this picture).

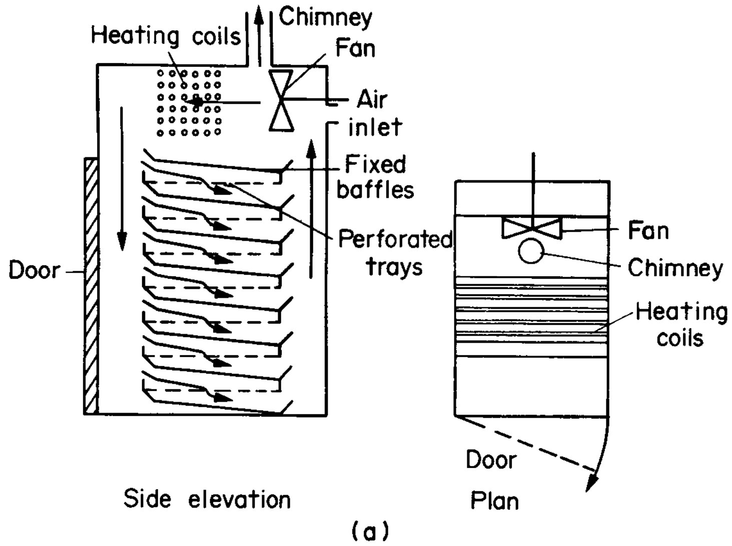


Figure 4.6 A often used batch drying system with a forced air flow through the bed

4.3 Design of the dryer at the Malindi site

The new container dryer at the Malindi site has been constructed, based on the components bought. A commissioning with a performance indication was net necessary, being build and in use by the same company. To understand the performance of the present dryer, experiments have been carried out.

In general, the Chilies will dry from 65-70% water to 10 – 12% water. So, the water evaporation is 60% of the fresh product flow with a fresh product/ final product factor = 2.5-2.8. 1000 g fresh Chilies give 380 - 400 g dried product.
A measured fresh/dry ratio is 2.51 (fresh 19726 , after drying 7866, after grading 6533 kg remains).

Estimation of the drying speed at Malindi
Using 7 kg of fresh material on each tray, each drying shift needs about 2200 kg. The water to remove takes about 57% or 1250 kg of the material in total. The energy needed for the evaporation of the water is 1250 kg x 2340 kJ/kg is about 3 000 MJ per shift. If only 2 shift will be used 12 hours are available with about 8 hours (28800 s) for the drying and the rest of the time for handling. In average a power of 100kW is necessary.

In Wageningen experiments have been carried out with fresh Chilies on a perforated tray (33% pores) with the air flowing upwards through the tray with an air speed between 0.8 and 1.5 m/s.
Fluidisation velocity of dry chilies is about 1.5 m/s in this set-up. Fresh chilies need a speed of about 3 m/s.

Experimental data for first hour of drying (1/4 - 1/3 of water removal) in the constant drying rate period in Wageningen, needing 5 hours to obtain complete dried Chilies:
-Air 60ºC with an air speed of 1.5 m/s: 0.006 %/s water evaporation/ initial load
-Air 60ºC with an air speed of 0.8 m/s: 0.004 %/s water evaporation/ initial load
-Air 80ºC with an air speed of 1.5 m/s: 0.01 %/s water evaporation/ initial load

Using these data for 0.8 m/s experiments for the case of the container dryer, gives a power needed of 300kW. Even in the beginning of the drying the power needed is less then the 500 kW, the oil burner can produce. Of course the heat exchanger must be able to transfer this power.

At Matu a constant drying rate can be seen up to 60% decrease in weight during the first 1000 minutes of 60000 s. Transferring these data to the specifications of the new dryer gives a minimum value, because in future open trays will be used. In the case of 2200 kg fresh material per dryer operation about the 1250 kg can be dried in 1000 minutes with a constant rate. This means that the heat transfer is about 50 kW, being much lower than the operations in Malindi are giving (300 kW) with the closed trays already.

In the empty container the air speed measured is about 1.3 m/s (design 2.5 – 3 m/s). Through the trolleys, through the slits and over the trays, the speed is higher: 1.7 m/s. When the trays are filled with Chillies the speed will increase, because less space is left to a maximum of 2 m/s. The flow is parallel to the bed with Chilies, creating less mass transfer and heat transfer then in the Wageningen experiments.

If the flow will be through the beds for optimal contact, the speed will decrease with a factor 4, giving a speed of 0.4 m/s. The factor is based on the cross section surface and the net horizontal surface, used by the trolleys. The higher pressure drop will also decrease the speed.

Water content with adiabatically heated air (no circulation)
The water content of the air is in climate of Malindi (T=28 ºC and 70 % RH) about 0.019 kg/m³ water/kg dry air (=1/1.28 m³ dry air). In the container is about 65 m³ air present. Using the Mollier digram and the adiabatically lines we can find the related dewpoint. This is 23.68 ºC for air of T=28 ºC and 70 % RH.
The maximum at 23.68 ºC (Tdewpoint) is about 0.021 kg/m³ according to the mollier diagram, so we can absorp adiabatically the difference between the maximum and the actual amount 65m³x0.002 kg/m³= 0.1 kg at 28 ºC. We need to absorp 1250 kg water because of the amount of Chilies.
If we heat up the air to 90 ºC we can absorp 0.0426 kg/m³. So we absorb 0.0426-0.019= 0.0236 kg/m³ (about 10x more than with ambient air). In this case we can remove about 1.5 kg water into the air of the container (assuming no heat transfer).
So we have to refresh the air about 1250 times at least in the 8 hours of drying. Better 1500 times in 8x60 minutes (= about 500 min.) taking a less efficient drying into account. So every minute we have to refresh 3 times the container volume = 300 m³/min = 5 m³/s spoil. In the two entries with 10 inch inner diameter, giving a 0.1 m² cross section surface, an airspeed of 60 m/s will be necessary for the case of adiabatically drying.

A calculation method is given in http://www.ringbell.co.uk/info/humid.htm

Water content with circulating reheated air heated air
Because we are recirculating the air, additional heat is put into the 90 ºC air. Because of the fast circulation it is assumed that heat is given to the air continuously. Therefore the air will not cool adiabatically to the wetbulb temperature. So the air will contain more water: 0.42018 kg/m³. This will give a 10 fold water capacity of 15 kg per container volume. We only need in this case 120 to 200 refreshments for the drying with an air inlet speed of 4-6 m/s.

Measurent of air velocities
The velocity of the air flows in the container have been measured using a propellor air velocity meter.

Measurements at Malindi site:
A)
Airspeeds in empty container with open lift:
Direct after heater: 3.3 m/s average (top and bottom heater 1.7 m/s, middle 4.3 m/s) , about 10 m^3/s through the crossection of the container.
Beginning of load place: top -0-0.4 m/s, middle 1.7 m/s, bottom 2.4 m/s
Middle of the container: 1.7 m/s average (top 0 m/s, middle 1.1 m/s, bottom 2.7 m/s) , about 9 m^3 through the crossection of the container.

The effect of the circulation ducts on the flow direction of the air can be measured.

B)
Air velocities in empty container with closed lift and recirculation and open inlet valves. There is no official outlet, but near the lift door are openings for the spoil:
After heater: 4 m/s. In the middle of the container: 2.1 m/s, about 11.5 m^3 throughput

It can be concluded that recirculation gives 25% higher throughput.

C)
Air velocities after 2 trolleys (one layer) in the container with open lift:
2.1 m/s average (top 1,7 m/s, middle 2.1 m/s, bottom 2.4 m/s), about 11.5 m^3/s througput.

The trolleys will homogenise the air flows. The pressure drop over 1 row of trolleys is not significant.

Air throughput in general:
In container about 10-12 m^3/s superficial for a cross section of the container of with 5.4 m^2.

D)
Air throughput from the inlet (equals the spoilage)
Two inlets with diameter 10 inch, giving a cross section of 0.051 m2 or 0.1 m2 for both.
Two ducts with a diameter of 20 inch or 0.20 m^2 cross section, giving 0.40 m2 for both the ducts, being 7.5 % of the cross section of the container.
Inlets 2x 0.65 m^3/s = 1.3 m^3/s (completely open valves)

E)
Refreshment rate from inlets
Fresh air/duct flow= 1.3 m^3/s /12 m^3/s = about 1/10 of the air flow is refreshed every second.
The container air will be refreshed every 65 m^3/1.3 m^3/s= 50 s or about every 1 minute. In 8 hours we have about 500 refreshements. One refreshment has absorbed 0.02 kg water maximally.
We need to absorb 1250 kg water for a full load of Chilies in the heated air of 90 ºC (15 kg per container volume adsorption capacity), so we need more than 120 refreshments in the ideal situation or refreshing every 4 minutes.

Taking all dimensions into account, it can be concluded that the dryer will work satisfactorily with the air velocities measured. For the dryer with almost a fluidised bed design when almost dried the flows need to be 4 times higher because of the larger horizontal cross section of the container.

Experiments during the drying of Chilies
Although almost no Chilies have been supplied during the visit, some experiments have been carried out. A high temperature of the sample gives a wrong measurement of the Aw value. Two undisturbed examples are given below.

Experiment A)
Drying 60 kg at 40-60 ºC in 12 hours.
This weight of 60 kg forms 60/3000 or 1/50 of the maximum load.
Refreshing rate is 40 times the container volume in 700 minutes or once every 15 to 20 minutes with 1/50 of the maximum load.

Experiment B)
Drying 72 kg in 4 hours on 29/8/08 at 90ºC with open inlet.
Aw in 0.95 (=fresh product) and the Aw value at the end of the drying sessions was 0.3. The product looks good.

4.4 Decontamination experiments

The heating of the Chilies at the start of the drying is usefull for several reasons:
-decontamination of the Chilies from bacteria, such as E. Coli, and moulds and yeasts.
-increasing the drying rate by destruction of the membrane with the turgor of the Chili cells.
-inactivation of enzymes, giving a loss of quality

Because the wet bulb temperature is lower than the minimal 72ºC, needed for decontamination, additioneel actions are necessary to aobtain a hugher temperature in the drier. The use of high moisture air is the simpels method, because the cooling down of the Chilies to the wet bulb temperatues is blocked. To increase the relative humidiyt RH steam is injected. In decontamination equipment based on the McCork process superheated steam is used, giving a faster heating of the spices and a dying afterwards. Bringing water into the dryer has often the opposite effect if the air heateers are not overdimensioned, because too much heat is necessary for evaporation, giving a cool down effect of the air.

Equator Products posseses a Kärcher steam/hot water pressure cleaner. For heating a gasolin burner is used. It was not possible to create steam with the Kärcher. The difference between water of 100 ºC and steam of 100 ºC is 2400 kJ/kg. With this amount of energy about 8 kg of water can be heated to 100 ºC.

Some experiments have been carried out with Chilies in a bucket, heated by the water of the Kärcher. The Chilies with a constant Aw of 0.956 have been heated up to 85-90 ºC in the water during 5 minutes (blanching). The effect of this treatment have been analysed after two several days. The blanched products kept a fresh smell and no additional black spots, while the untreated Chilies in a closed bag start to give the off-flavour caused by fermentation.
Became blanching at 90C with a lot of broken chilies

After improving the performance of the Kärcher, it has been tried on Wednesday evening to use the injected water into the drier. At 20.15 hour the experiment started for a hour. The inlet valves and the slab above the lift were closed.
The boiler water was 90 ºC. The internal drying air never became hotter than 75 ºC.
3x 20s with 3 l water of 85 ºC was injected, giving a total of 9 l water. The water was flowing on the floor of the dryer. The RH of the air was about 35-40% at the most according to the recorded values and was decreasing to 25% after stopping the boiler for the night. The temperature of the drying aie was decreasing after each injection, but was not fully recovering to the original teperature.
The air never became completely humified by 90 ºC, giving inactivation. How ever, these conditions obtained were optimal for blackening.

A tray with Chilies with a Aw value of 0.55 had some sever blackening on Wednesday. On Tuesday evening thise tray was already drying with an Aw of about 0.8. The Chilies observed were squeezed and intact. So it looks like a enzymatic reaction (Polyphenoloxidase).

4.5 Dryer control strategies

Because the drying shifts change in circumstances every time, but have to be reasonable constant in a whole, some main strategies to control the drying can be generated. Objectives for the control are:
-a short drying cycle, using the highest possible air temperature
-a good quality of the Chilies, needing a lower temperature and the end of the drying
-obtaining an end AW for the dried Chilies of less than 0.60, favourable 0.55

It is possible with the logger, reading the results off-line, the Tair and the humidity in the recycle duct and before the heat-exchanger. It's also possible to measure the temperature and RH of the ambient air.
If necessary will be possible to measure the Aw of a sample during a drying cycle, to obtain insight of the process. It's also possible to measure the weight change during the drying, even in line with load cells under a trolley or with a special sample tray. It's also possible to create a special sample holder in the container, that can be retracted during the drying for weighing and inspection outside the dryer. For the measurements in the container the air flow has to be stopped for a moment.
Making a opening for a sample holder, it's also possible to measure the surface temperature of the Chilies of a sample visible from outside, using an infra red temperature meter. If this surface temperature is increasing the boiler water temperature has to be lowered to obtain a constant temperature of the product. The air temperature will never be higher than the boiler water temperature.

The end of a drying cycle can be expected if the RH of drying air does not change much anymore at constant Tair or the temperature of the air will increase, because the evaporation is not cooling down the air. A defined end value for the Aw of the Chilies can obtained by bringing the T and RH of the drying air in equilibrium with the desired Aw for the chilies.
For that reason a table is necessary with the equilibrium values of thr Aw for some temperatures, used in the dryer. Temperatures between 40 ºC and 70 ºC are usefull. At 28 ºC the equilibrium value is about 0.67.
Because every day the same will happen in future operations, an estimated guess of the drying time will be learnt.

Evaluation of every drying cycle is helping to create a databank for evaluation in real time the process in future. For that it is good to measure the Aw and weight of a load of products at the beginning and at the end of every cycle.

4.6 Packaging the product

After drying the Chilies will absorb water again in the climate of Malindi. Therefore the product has to be protected for the moisture. Also oxidation reaction will decolour the product. The packaging is created by two packing bags of monolayer Polyester. A bag with a thin layer is put into the bag with a thick layer. The last bag is the standard product packaging, used in the past.
An experimentt has been carried out to observe the moisture transport at ambient temperature into the two different bags with Chilies.
The experiment using 0.5 kg of Chilies for each of the three bags started Thursday at 18.00 hour with the other measurement after a week exactly. Two bags have been tied up with a strap as usual. The closed bags are only measured after a week, because the changes are expected to be small and the handling of the bags will give too much disturbance. It was planned to measure also after two and three weeks after my visit. No further data has been obtained how ever.

The results are:

For the two tied bags and the open bag:

Packaging	Aw at start	Aw after 7 days
Thick PE	0.419	0,509
Thin PE	0.419	0.484
none	0.419	0.670

The open bag:

Days stored	Aw
start	0.419
1	0.464
2	0.583
3	
4	
5	0.686
6	0.663
7	0.670

After a week the equilibrium Aw for the Chilies seems to be around 0.67, being higher the limits for storing the Chilies. This resulting Aw value is high enough for the growth of moulds. The equilibrium depends on the weather. Because the measured values change less than ±2%, small difference in the measurement are visible. Especially the equilibrium time needed is important, while the automatic extrapolation mode of the Aw meter can't be used.
In the bags the Aw value increases also. It can happen that the closing of the bag with the strap is defining the Aw value measured. Still the moisture content is beneath the specifications necessary after a week, giving no problems.

5. Alternative energy use

5.1 General
In Africa and Asia most drying of food products is based on the use of direct solar energy. Due to the direct contact of the food with the open air, infections such as Salmonella or E.Coli form a threat. The European Union dictates that the drying needs to be an indirect closed heating system. Indirect heating is necessary because of possible residues from the fuel.

5.2 Solar Energy
Kenya is situated near the equator and makes the use of solar energy very interesting. At the Matu site the incoming air is heated by the sun, using the roof of the nearby building. For the Maindi site the possibilities have to be investigated.
The geographical coordinates of *Malindi Airport* are -3º 13'46" S (-3.229306) and 40º 6' 6" E (40.101667). Equator Products is on walking distance to the airport. The RH (Relative humidity) is 74 – 78 (average) – 81% with temperatures between 25 and 30 ºC and 8 hours of sun every day in average. The airport is situated several kilometers from the sea and is almost at sealevel (+24 m).

In Nairobi, the nearest main city, the solar energy is during every day about 5.3 kWh/m², giving approximately 2000 kWh/m² yearly or 7000 MJ/y m², being the double of the possible sunlight recovery in The Netherlands (1 MJ = 0.2778 kWh, 1kWh=3.6 MJ, 1Wh=3.6 kJ). Diffuse sunlight at cloudy days gives about 15-20% of the maximum energy to the the surface.
In general the maximum energy uptake above the atmosphere is 1367W/m² giving an energy of 1 kW/m² at sea level.

Solar generation of electricity
Phota voltage cells have a conversion efficiency of about 15%, 22% at the best, with a covering area of 80%. A new generation of PV cells is under development and will be available in a few years. The price will become much lower and the cells are less vulnerable. The amount of electricity used is not high at the site. The main problem is the permanent availability. The delivery is also not guaranteed with the of PV cells.

Solar heating of water
Sun boilers are common and also in use at the Malindi site of EP. For use of the solar energy for drying a cheaper system has to be developed. A standard sun boiler is producing 0.7 kW/m². It can use water direct or indirect with a special gel. The collector can use vacuum and glass tubes, making is more vulnerable. Metal tubing is more rigid.
The purpose is to buy a simple system of around €800/m².

A simple design is based on the use of black Polypropene or LDPR piping with a diameter of 20 mm with a wall thickness of 2.2 – 2.7 mm. The piping is fixed to the blackened soil in a dense parallel and covered with tranparent plastic for isolation. Circulation to a isolated vessel (or to the boiler)can be by convection or by forced convection, using a pump, . The technique is used for acquifiers for heat storage.

Solar heating of air
At the Matu site the heating of the roof is used as an heater for the drying air. This is not directly possible in Malindi, being an open structure now. Indirect sun drying is also possible by creating a simple collector using plastic. With a solar energy density of 1kW/m² a surface of at least 300 m² is necessary, being twice the surface of the roof of the building.
Using the roof can give a support heating, but the surface is not large enough for complete indirect sun drying. The amount of sun hours in Malindi is also more variable than in Matu.

Solar heat storage by Zeolite

Zeolite is a cheap absorber, using a molecular sieve structure with small channels in which molecules fit almot exactly. Originally Zeolite is a clay. Now-a-days Zeolite is also artificially produced for absorbing different types of molecules. Water is the most often used material to absorb.

A 2 kg sample of a Zeolite is present at the Malindi site, stored in plastic bottles.

5.3 Biomass energy

The most sustainable and cost-effective method for heating is the use of a biomass burner. A comparison of the conversion energies of different materials is given here under.

General data:
Water evaporation: 2200 – 2400 kJ/kg depending on the temperature

Conversion energy per unit of material (approximately):

elektricity	3.6 MJ/kWh	(by definition,
oil	42 MJ/kg	12 kWh
Cokes	28 MJ/kg	8 kWh
biomass	12 MJ/kg	(9 – 17 kWh)
dry wood	20 MJ/kg	max
wood saw dust	16 MJ/kg	

Small generator gives about 35% efficiency, Efficiency biomass burner: 40%- max 55%, rest energy to be used for heating.

3000 MJ energy per shift of drying a full container is needed at Malindi. Using oil about 150 l is necessary by an efficiency of 55%. The biomass burner needs about 600 kg of wood or nut shells per shift (30% efficiency).

The oil burner is functioning at the Malindi site. A biomass burner is refurbished in Rijssen to be shipped to Kenya.

6. New products

Although the Chilies are a good product with a high added value, available for processing during the year, it is good to explore options for more products for porcessing. In the list below some new crops are suggested.

Suggested new crops for processing:

	Blanching	Osmotic	Hot-Air drying	Vacuum frying/ Standard frying
White Cabbage	**X**		X	
Onion		**X**	**X**	**X**
Carrots	**X**		X	X
Eggplant	X	X	X	X
Courgette	X	X	X	X
Okra	X		X	X
Tomatoes		**X**	X	X
Other chilies African Bird's Eye chilies (OP), (Hybrid) High pungency chilies, Habaneros, Cayennes, Ancho/Poblano, etc.			X	
French beans	**X**		**X**	
Banana		**X**	X	X
Papaya		**X**	X	X
Mango		**X**	X	X
Melon		X	X	X
Pineapple		**X**	X	X
Jackfruit		X	X	X
Strawberries (to be tried)		**X**	X	X
Raspberries		X	X	X
Macademia			X	X
Cashew			X	X (Sf)
Cashew apple	X	X	X	
Herbs			X	
(Flowers*) not*			X	
X: important aspect to be understood				
Most important products: Chilies, white cabbage Hot air drying: White cabbage, french beans, chilies (Bird Eye and Habanero) Vacume frying: onion, banana, pine apple, papaya, orange melon Frying: cashew nut				

Hot air drying is interesting for other Chilies and for vegetables.
To obtain a well structured chip to eat, fruits can be best end-dried using vacuum frying.

Vacuumfrying is used for pine-apple and apple in India, China and Israel. Also Mango and banana form a good raw material for vacuum frying and are availabel.

7. New processes

The products, mentioned in the former chapter, can be processed with new processes for Equator products.

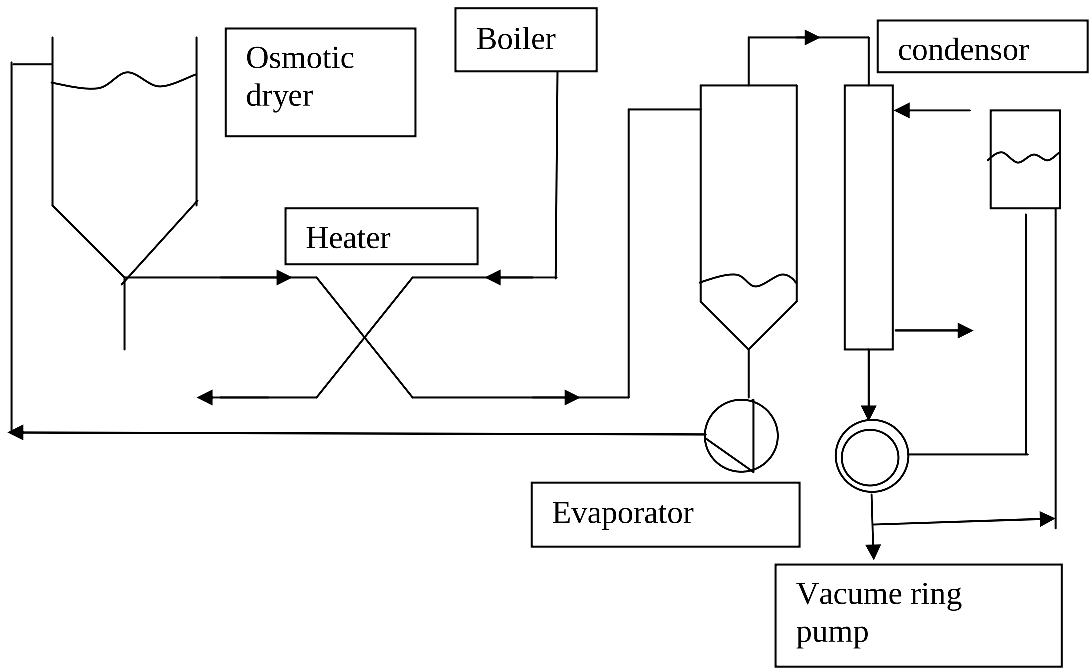
7.1 Preprocessing
Products: White Cabbage, Courgette (Kool, courgette)
1000 - 2000 kg/hr for the future per location
Cutting: belt cutter 1 Dimension, 2 dimensions or 3 dimensions (blocks)
Washing in bassin with belt (second equipment) Same as osmotic drying?
Surface drying: about 100 kg batch centrifuges every 5 minutes charging (2x, also to be used for frying?) giving 24x100 = 2400 kg
Sulphite necessary?
First experiments in 2007 at Voortman at Rijssen.

7.2 Osmotic drying
Input: 200 kg/hr – 300 kg/hr fresh material with 85 – 65 % water
Output: 50 kg with 25 - 30% water
Residence time less than 1 hour, Temp. solution 60 ºC.
Tube, belt or batch (12 centrifuge baskets) container: open container with belt transport preferred, additional belts for input and output.
Dimensions for instance: 6m x 0.5 m x 0.2 m

Water evaporation 150 kg/hr = half of in input (about 1 kilo stream gives 1 kilo water evaporated)
At 60 ºC also water will evaporate in the container without evaporator
Energy necessary: 150 kW hot water 95 ºC

For the heating of the osmotic solution from 55 ºC up to 85 ºC, an indirect heater will be used with water from the boiler resevoir with a temperature around 95 ºC.

7.3 Vacuum frying



Frying forms a quick drying system, giving a more porous and crispy structure, because of the fast evaporation and low final moisture content. Also the taste of fat can be attractive, but often not in too high quantities now-a-days.
It is better to predry the product to intermediated moisture contents around 45% with a cheaper process, such as air drying or osmotic drying. Vacuum frying will go faster at low temperatures, giving also no brown colouring. Therefore vacuum frying is attractive for fruit and vegetables to create crispy chips or easy to hydrate dried vegetables. Fat penetration into the tissue happens especially after the breaking of the vacuum. To obtain a low fat product it is necessary to maintain the vacuum while the product is freed of additional fat. Normally this is created by a centrifuge.

A small batch centrifuge vacuum fryer, constructed by Feltracon, has been bought with a 200 mm diameter basket, combined with vacuum oil storage.
Every frying cycle with 5 kilo intermediated dried product takes 3-4 minutes with 10 – 15 s net frying time. Using the fryer 10x per hour give a throughput of 50 kilo/hour maximally.

Specifications for the process:
Possible products: Chili, Onion, mango, papaya, pineapple
Predrying by currently used tray drying to 45% moisture content, later with osmotic drying (see further in the text)
Input 50 kg fruit per hour with 40 – 45% water
Product temperature less than 112 ºC, 10 – 15 s, 40 mbar
Frying oil at start 130-140 ºC, at end of frying around 130 ºC. No heater in the centrifuge.
Heater (10 - 20 kW) in the oil storage tank, not in the centrifuge.
Output: 20 - 25 kg with 2.5% water (max for crispiness).
Specific weight of the fried products 50 – 100 g/liter
Standard packing unit: 30 g in air with air and light tight material.

Other machines build by Feltracon, giving the possibility for upscaling, are:
For India company delivered: Input 35-50 kg output 20 kg/hr
Feltracon 200 (mm) see above
Feltracon 400 (mm) vac. (40 l): 2kg product per batch
Feltracon 500 (mm) vac. (60-80l): 4 kg

Vacuum is delivered by a waterring pump with condensor (with cooler) before the pump to reduce to amount of water vapour (vacuum depends on temperature of the water in the pump, normally around 17ºC and below 40ºC.
Vacuum of waterringpump has to be lower than 180 mbar (60 ºC is max.).

As oil fractionated Palm oil will be used. Fractionating means the separation of the hard fat from the liquid fat at room temperature.
The oil can be stored in the tank beneath the Feltracon centrifuge or above the centrifuge.
Oil has to be heated by a electical heating element to 150 ºC. During the frying the oil will cool to 130 ºC. The product will absorp about 10% fat, so 2 kg per batch of 20 kg product.
The restored oil has to be cleaned from water, particles and solubles (the mud) by sedimentation, as shown in the drawning and/or by a filter. The oil can circulate through the filter and/or pass to a store tank above the Feltracon. Transport will be by gravity in that case.

To assure a good quality of the oil a free fatty acid test is needed. This is a standard test (dielectrical tester for instance).

Normally, the hot (and cleaned) oil from the lower storage will be “pumped“ into the Feltracon by the vacume. That takes about 20 s. The frying starts because of the contact with the product. The ending is by opening the valve to the lower tank. Oil will leave because of gravity.
The lower round storage tank is about 250 l. If there is no upper storage tank, also a heater has to be mounted on the bottom in the vessel in the oil.

It is also possible to use combine the heater tank with the storage tank.
A modfied pilot plant has been built at the site at Rijssen (NL). A modified control procedure has been written down. Some pictures of the plant and the procedure list are given in attachement 3.

8. The Malindi site

8.1 History and visit

Status
The Malindi site dryer has been established mid 2008. Originally the dryer at this site was planned to be used for the production at a large farm in the west of Kenya. This production was not successful and the possibilities for setting up production in the east at the coast showed to have a better perpective. At the moment of the visit to Malindi around the beginning of September the site was initiated less than two months before. Four trolleys with closed trays from the dryer at Matu were in use. Other process equipment was not available, except some tables. Some measuring equipment, such as an Aw meter, some temperature meters (also infra red), an air velocity meter have been bought. Weighing devices missed the power supply or battery and are not calibrated. The collected production was less then 300 kg per week at the time of the visit. During the visit more equipment started to operate, but most machinery has to been build and employees had to start freshly.

During the visit the Malindi site was still under construction and the supply chain was starting to become operational. New trolleys for the new container dryer and other equipment still had to be build in that time. About 300 kg fresh Chilies per week were dried, using old trolleys from the Matu site. For the scale of the processing units it was supposed, that perhaps 40 tons per week had to be dried before the end of the year. In the beginning of November, actually around 4 tons per week were processed for both the sites together, giving no problems in processing.

The process of gaining contracts with the small holder farms was going on. The contracts give the farmer the guarantee of the collection of the harvest Chilies for a given price (around 65 Kenyan Shilling (100 KS = 1 €), being the double price in comparison to the competition.

Based on the contracts a production of 40 tons per week during the first full harvest of the young plants was expected and therefore to be taken into account. In reality this will be lower and about 4 tons a week is a good estimation. The export will be about a container every month.

There is competition in Keya by another company, using farmers dried Chilies. This chain has been set-up by a German advisor via a Kenyan company. The price paid for the dried material is about 30 KS per kg fresh material. The packaging of the product looks professional and seems to be made of a multilayer PE.

The visit from 25/08/2008 to 5/11/2008 was directed to the understanding, such as the measuring the capacities, and by that of the optimisation of the new dryer, constructed by the Voortman companies, and to work on decontamination as far as the available equipment made this possible. A communication (letter of reference) about the just planned visit has been sent in draft (attachment 1, based on the discusion during the meeting of 21/7/20008) without reply. During the visit daily updates of notes about the experiments and calculations have been given to EP. Most help and communication about the dryer, about analyses and about the supply chain has been with the employee stayed at EP during my visit, coming from the Matu site.

Also the use of alternative energy sources forms a objective of the project. The weather in Malindi is less favourable for solar energy than in Matu, although enough solar energy is available with clouds. Due to the start phase at Malindi, experiments were not possible. A standard solar boiler for hot water has been installed.
Only the oil boiler is in operation and became fully steady state usable during the visit.

The biomass burner is present in Rijssen, to made ready for cocos nut chips.
Further the processes in the supply chain have been discussed, resulting in the initiation of a project manager file for coordinating the tasks to do and I created a first lay-out for the very near future in discussions at Malindi (see 8.2). This lay-out is easily to change. The dimensions have been made on scale as much as possible. In the mean time the cool container has been bought. This idea of temporary storage of fresh product, as also used at the Matu site, has obtained attention during this visit.

Microbiology, HACCP and decontamination
Questions about the microbiology came up in the past years. Some general counts of dried Chilies for export are made by a third party. A microbiology laboratory does not exist and elementary facilities are missing, but will be created in the near future.
Some experiments have been suggested earlier to obtain an answer on the questions about infections in the processing at Matu, again suggested in the communication about the visit at Malindi. Clearly, these experiments are possible after establishing a laboratory in future or samples have to be given to this third party, being the original recommendation.
Some of the problems will arise by lack of cleaning unexpected places, such as the roof or piping. Especially places with a cold spot are well known to give trouble. At Matu the roof forms such a place.

Cold storage is necessary to control mould growth and enzymatic reactions.
Storage at 4.4 ºC in air (closed bag) of chilies with the stem/stalk connected to the Chili, gives good quality after a week (no black colouring) at AFSG.
During the visit an additional cold storage for the incoming Chilies has been suggested to overcome periodic undercapacity of the dryer. The cold storage container is also usefull for temporary storage at other moments during the the processing.

The HACCP system for Equator products has been founded by the HAS Den Bosch students Hanneke van Breda and Rianne Lamers in 2006. Andries Trenning has elaborated the system and worked out the laboratoria facilities. I was only able to make the analyses more easy to use and to discuss the procedure for analyses.

The HACCP is necessary for the certification of Equator Products (Eurepgap).
Controlling the production of Aflatoxin by moulds after harvesting is a important objective, therefore an Aw < 0.55 (0.6 accoording to specifications) is used in the packed product.
Coliforms (E Coli) often give infection because of lack on hygien during harvesting. But also not enough cleaning in the processing can give this problem (humid places in the air flow for instance, such as the solar roof)
Salmonella infection is important, but not a real issue.

For the sake of hygien also decontamination/pasteurisation has been checked, but no steam generator was available at the Malindi site. Creating steam needs a lot of energy and is not possible to generate by the boiler connected to the dryer. The available Kärcher cleaner produces hot water, that can be used for cleaning equipment.

The administrative systems, necessary for tracing, as used for Eurepcap cerfication, are handled by hand in this moment. Computerised adminstration has to be worked out to make handling on a larger scale possible.
Also other management activities has to be structured and put in archive, as needed for the HACCP system.

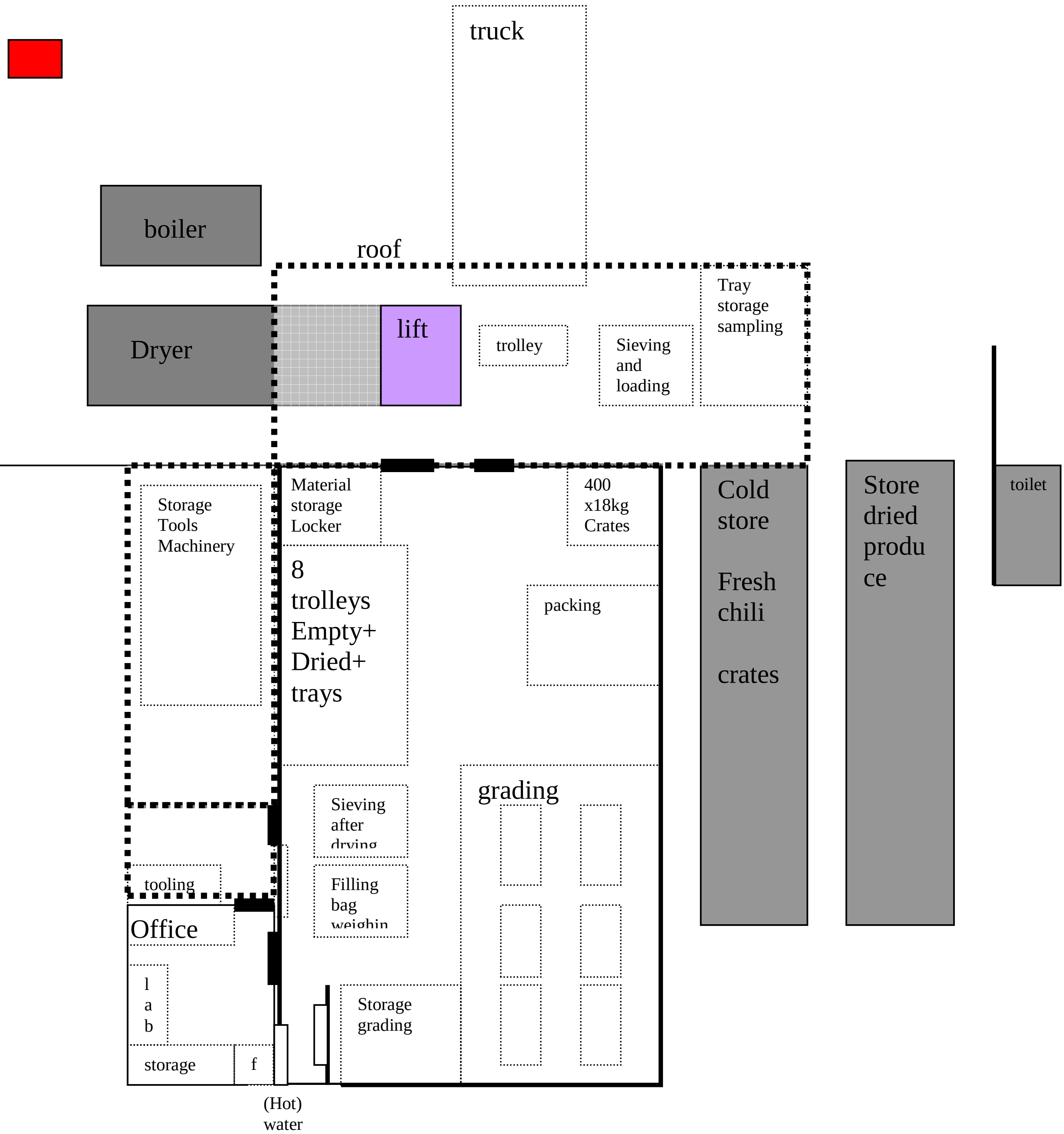
The facilities at the sites are limited, also because the related expertises have to be learned by the owners. Facilities, including equipment, space, ingredients and trained manpower, for microbiological experiments were, and still are, not possible   How ever, the efforts are more directed to the main path of creating and understanding the logistic infrastructure with the completion of the most important steps as far as possible, being the real objective during the visit.

8.2 Suggestion for the lay-out of the EP Malindi site

To speed up the start-up of the new site, a lay-out has been drafted, as visible in figure 8.1.

Figure 8.1 Proposal for a lay out for the Malindi site of Equator Products

Building: 9.78 m x 15.84 m internal.
Grading table 2.32m x 1.10 m, 3 tables behind each other makes 7m



8.3 New processes at the Malindi site

In the neighbourhood of Malindi many Cashew trees are harvested. Some processing of Cashew nuts is going on. The Cashew apple is not used, also because it needs knowledge to harvest at the right moment to minimise the bitterness. It's a possibility to process at this EP Malindi site Cashew nuts. This processing is different from the present operations going on and also different from the proposed preprocessing steps. For instance, The Cashew nut is fried and the vacuum frier has to be used at elevated temperatures. The equipment has to be adopted for this purposes.
Because of the focussing of the efforts on the present operations and the enhancement of the suply chain management, it has been advised not to start cashew processing.

The equipment for the pre-processing is in The Netherlands and not available for try-outs.
In 2006 the students from the HAS have described the pre-processing of several products, present at the farm in West Kenya.

9. Conclusion and further work

9.1 Conclusions

Dryer
-The boiler has enough capacity: 500 kW (300 kW needed), but has set to a water temperature of 90 °C, decreasing it's capacity for heat exchange.

-The heat exchanger gives not enough heat to the dryer air at 90 °C to obtain a drying rate necessary for 40 tons per week. It needs higher water temperatures for better energy transfer to the drying air. For lower throughputs, as the original design

-The heating by the dryer goes slowly (40 °C increase in one hour with almost no water to evaporate in the dryer).

-Airflows in the 65m³ container:
In circulation:
12 m³ through the dryer, with a inlet flow of 1.3 m³ . The superficial air speed in the container is about 2 m/s.
No circulation:
10 m³ through the dryer.
The pressure drop over the fans looks to be less than 0.1 bar.

-The refreshing rate of the air seems to be good enough, if we assume that the heating of the air is good enough to keep the temperature of the air at the same level despite the evaporation energy needed (otherwise we obtain an adiabatic cooling as normal in drying operations).

-Amount of refreshments needed about 1200 container volumes at 90 °C air under adiabatic conditions. If the heater gives enough heat and the lift strip is open than only 120 refreshments would be necessary while the moisture capacity of the air is increasing to 400 g/m³ at 90 °C.

-It has been suggested to use open trays with trolleys with closed walls (and rubber strips) to force the airflow over the trays.

-For a better exchange of heat and water around the chilies it is suggested to put strip every second slit above the tray in the trolley in the flow direction, with a same system at the other flow direction, but with one slit change. So the air will be pushed trough the trays.

A later possibility (with higher capacity fans) is to bring the air under the trolleys (all sides closed) with the exhaust air at the top. No return ducts are needed in this case.

-About 100 l diesel is necessary to dry the chillies within 8 hours at 90 °C (if the heater allows this). A full load has a value of 180.000 Ksh. The diesel will cost less than 10.000 Ksh. So the costs compared to the added value is in good proportions.

-Dryer control strategies:
.The simple method is to dry always the same amount of chilies with control on the temperature of the drying air. The amount of diesel needed is related to the evaporated water, but also the drying time.
In the first period of processing the fresh Chilies, several Aw measurement are necessary during the drying with a standard load of Chilies (8 trolleys), but this will decrease rapidly, obtaing enough data.

.More advanced is to look to the Relative Humidity of the dryer air. If the value goes down, the evaporation is slowing down and the temperature of the Chilies itself goes up. By decreasing the air temperature a new equilibrium will exist. The lowering of the temperature has to stop at such an air temperature and RH of the air that the chilies will end at an Aw of 0.55. The negative effect of this method is the long drying time needed. Also the absorption curves for the Chilies has to be known.

.The end of the constant rate period can also be observed by measuring the surface temperature of the chilies. By using an infra red temperature measurement. Up to the moment of an increase of the temperature above 65-70 °C full drying is possible. In the tailing period the temperature of the chilies has to be observed and the air temperature decreased to a constant temperature.

-AFSG was involved in the design of the trays last year, however for the basic calculations for the dryer design no involvement has been requested. The equipment has not been tested in The Netherlands for the specifications.
In this mission it has been tried to find the values needed to calculate the drier design. It seems to be necessary to change the basic design of the drier. Especially the fans and the heater are small in comparison to the 1200-1400 kg to evaporate at full load.

-In future a belt dryer is possible for higher throughputs. A continuous supply of raw material is necessary. The handling in relation to the drying is more simple, but the small scale tracing within the present supply system will be more difficult.

Black spots on the Chilies
-Blackening is caused by enzymatic reactions (of plant and micro organism).
Sqeezing/bruising the intact tissue favours the blackning.

- Blackening will go faster at higher temperatures, especially round 50-70 °C. To stop the reactions high temperatures are needed. However during the beginning of the drying the chilies never become warmer than about 65-70 °C, because of evaporation. (Wet bulb temperature) Because heating goes so slowly, the blackening is favoured.

Decontamination
- a fast inactivation of micro organism or enzymes is not possible in the present configuration with a too slow heating power. It has to be faster than the reactions at elevated temperatures, therefore the present heating has to be faster.

-Blanching the chilies at 90 °C:
The non steamed samples start to smell fermented after two days
Blanched samples smell just a little bit, look good , no additional black spots.

Packaging
- The PE foil gives a notable water vapour diffusion.
It seems to be that the equilibrium Aw for dried chilies is about 0.67 at 28 °C and 70% RH.
Storing in closed bags is necessary.

9.2 Future work

In the meeting of 21/7/2008 a follow-up proposal has been discussed, as seen during my visit at EP (with A&F as a partner).

Future work is needed for:
-designing the international supply chain for Chilies
-Structuring and computerising the administration for the supply chain
-enhancing the heat-exchange capacity of the dryer
-installing a biomass burner at the Malindi site
-installing the pre-processing
-installing solar energy systems

Attachement 1

Mission objective:
Optimisation of the processing of Chilies at the coast location.

Objectives:
-To enlarge the capacity of the dryer system at the Malindi site by creating three shifts a day with 5 hours of drying to obtain a production capacity of about 50 tons per months. Based on the experiments improvement of the installation will be necessary to obtain a better heat transfer to the chilies from the air (See additional note 1).

-To decontaminaat the chilies in the first phase of the drying. This decontamination by heating will be created by closing the air spoil of the container and possibly by injecting steam or spraying hot water. The target is to obtain a temperature of 80 degree during 10 minutes. The quality of the chilies is determing the real decontamination process.

-Additional attention has to be given to:
-food safety (indirect heating, avoiding contamination, especialy Coliform infections)
-work book for the processing (in relation to ISO certification and HACCP)
-Quality control facilities
-processes related to product development (Cashew)
-solar energy input and the use of Zeolite.

The process control will be kept as simple as possible.

Necessary are:
-Infra red temperature measurement of the Chilies during drying on the trays. The moment of the constant drying rate will degrease and the temperature of the Chilies goes up can be determined. From that monet on the air temperature will influence the Chilis temperature. (Conrad)

-sensors for the Temperature (T) and Relative Humidity (RH) of the air.

-Measurement of microbiological decontamination, using a third party or with a kit (via Andries).

-weighing between 100.0 g and 10.0 kg (and total weight of dried batch)

-Several meters of black plasit tubing (1 – 2 inch)
-black plastic (as a underground)
-glass plate

Experiments:

A Microbiology:
1)
Microbiological counts (total/ Coliform) of same batch of Chilies after harvest (or even before that harvested using special care when creating a sample), before dryer, after dryer and during packaging. If possible also after a week of storage.

2)
Measuring the microbiological counts (total) before and after the drying, using high temperature/humid air regime in the beginning of the drying.
Optimisation decontamination:
Measuring T air, RH air (in and out), T chili (from outside container) and t.
Variation in: T air in (air heater), velocity air, RH (by injection of water)

B Optimisation drying:
Obtaining maximal drying capacity.
Measuring T air, RH air (in and out), T chili (from outside container) and t.
Measuring weight of Chilies on several trays
Variation in: T air in (air heater), velocity air, RH

If possible data storage (what is now available?) and process control

C: innovation in drying
1)
Zeolite energy storage to obtain better drying during the night
Samples (2 x 1kg) are taken with me (possible?)

A tray will be filled with zeolite. Weight increase will be measured.
Desorption of water will be measured in the sun under a glass plate.

2)
Solar heat:
-measuring the temperature increase of the water flowing from the boiler vessel to the dryer in a black tubing under glass or
-measuring the temperature increase in a black tube with enclosed water.

Note 1: estimation of drying speed

Per shift: 8 trolleys with 38 trays (20x120x2.5 cm) of 7 kg fresh product gives 2128 kg. Water to remove: from 65-70% to 10-12% in product gives a water flow of 60% x 2128kg = 1277 kg. Evaporation at 70 degree Celsius= 1277kg x2340 kJ/kg = 2988180 kJ (3000 MJ) per shift or 3x 3000 = 9000 MJ per day.
For every shift 8 hours are available, including handling. For drying there is at the most 5 hours available (18000 s) Power needed (average) 500 kW.

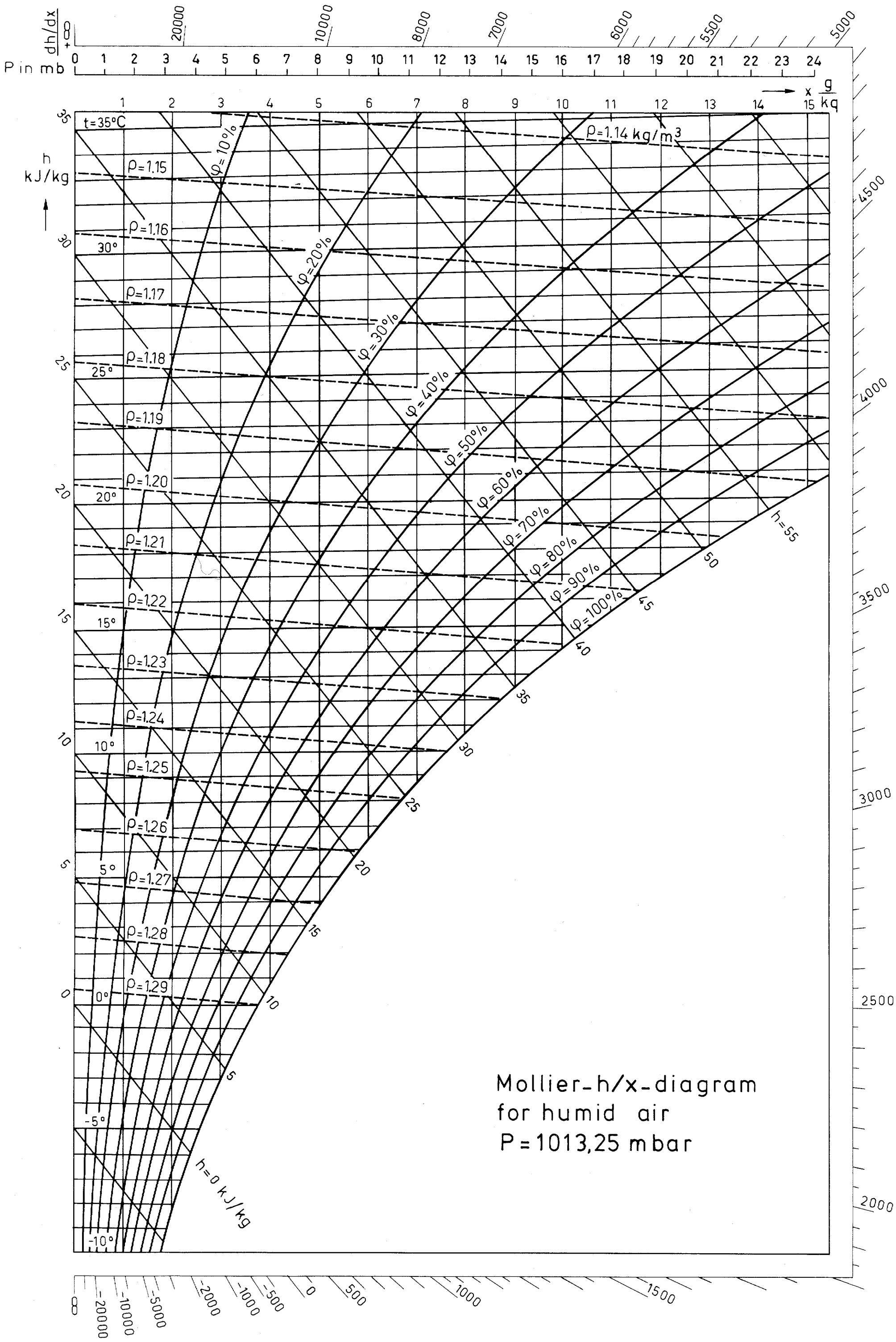
Experimental data with a perforated tray (air flows through pores) for first hour of drying (1/4 - 1/3 of water removal) in the constant drying rate period:
Air 60 degree Celsius with speed 1.5 m/s: 0.006 %/s water evaporation/ initial load
Air 60 degree Celsius with speed 0.8 m/s: 0.004 %/s water evaporation/ initial load

In the container the airspeed is about 1.3 m/s. This air is flowing over the chilies on the tray.
If the air is flowing through the tray, the speed will be 5/120= 0.04x 1.3 = 0.05 m/s
The fluidisation speed for dry chilies is above 1.5 m/s.

Maximal power uptake for drying in the container, with mass/heat transfer limitations based on experiment with 60 degree air 0.8 m/s: 0.00004 x 3000 x 2340 = 300 kW. This is less than the average power calculated to obtain a batch drying within 5 hours. Conclusion is that the air temperature has to increase to 80 degree to obtain more transfer (experiment 80 degree 1.5 m/s gives 0.01 %/s). Also the air/chili contact can be to limiting for the transfer of the heat because of the laminar flow behaviour.

Attachement 2

Mollier diagram



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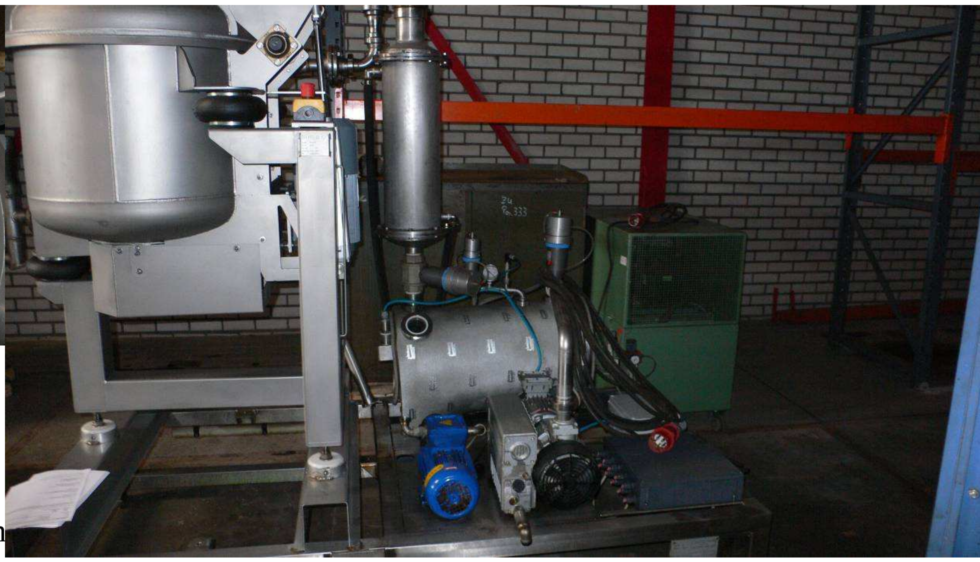
Attachement 3

Vacuum fryer Equator products
May 2008 vs5 control procedure



Processin

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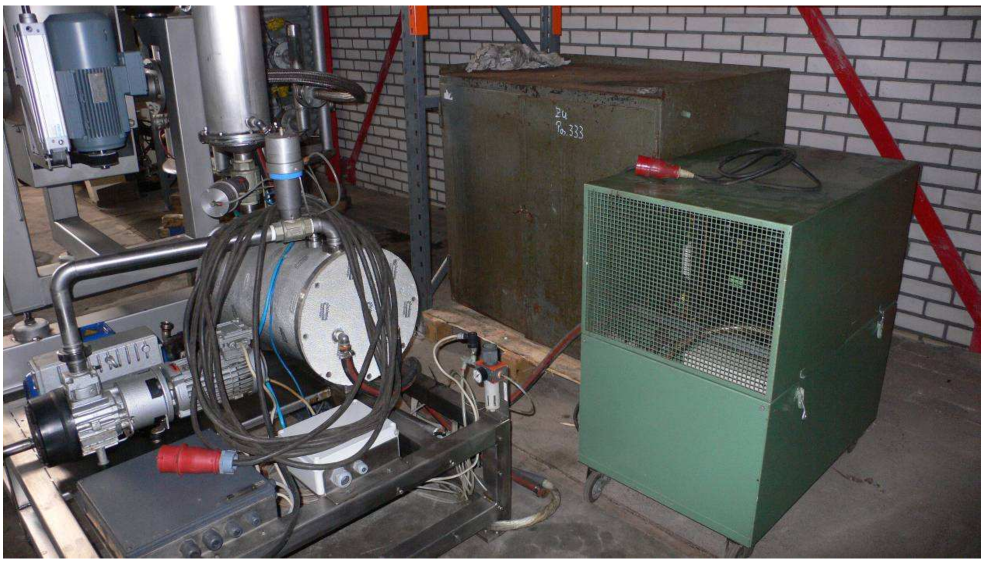

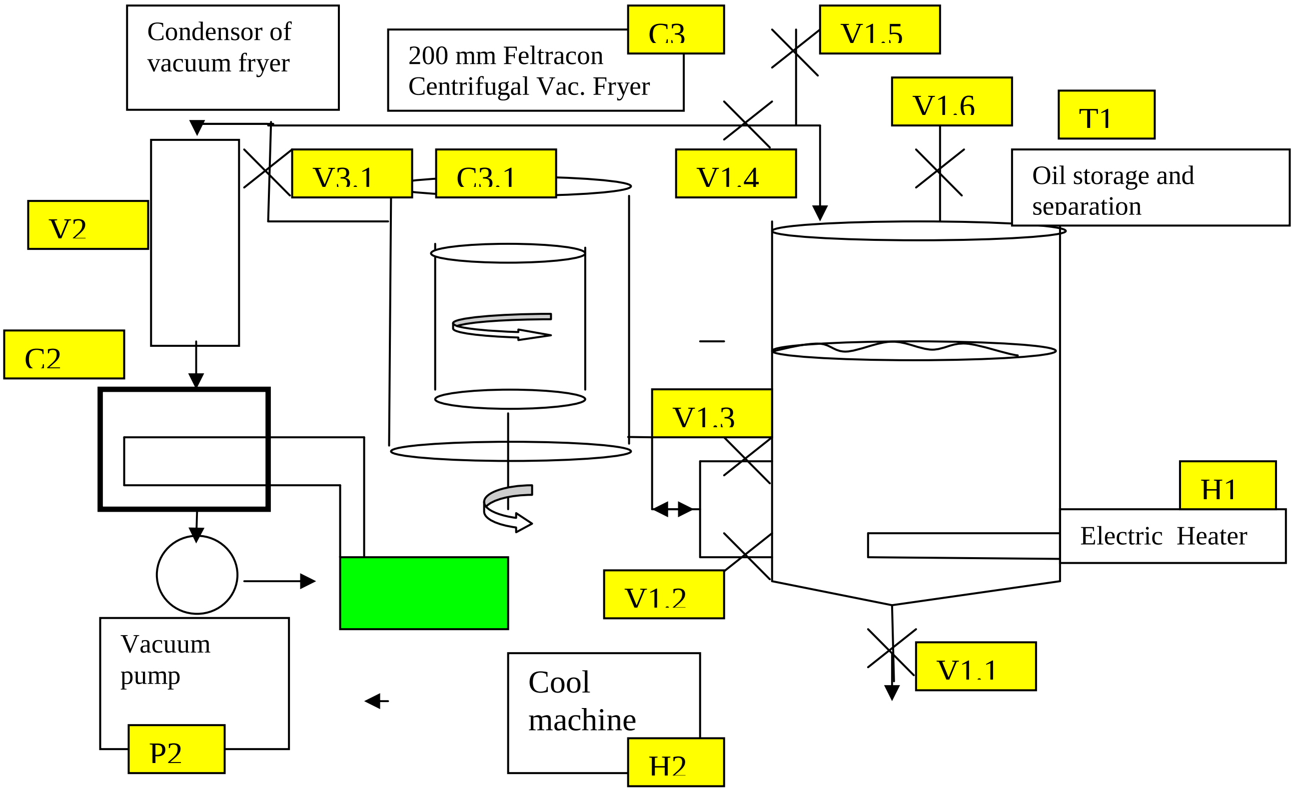

H1: not present
V1.1, V1.4 V1.5 V3.1 : not present
Safety valve T1?
Pumping fresh oil to T1?

Procedure vacuum frying:

Settings (S: setting, anders alleeen aflezing)
SL1: level indicator separation tank. (kan visueel met glas)
controle bezinksel:
Bij een capaciteit van 20 kg verdwijnt hier maar een paar kilo/liter per uur.
Niveau houden dat voldoende is en geregeld bezinksel handmatig spuien en dan weer aanvullen tot niveau.
SL2: level (low/high) higher heater tank T1.
Laag niveau door de hoogte van de afvoer pijp naar de frituur, zodanig dat de vloeistof om de heater in de tank blijft staan
Hoog niveau: middels overloop bewaken of met een sensor als aangegeven. Bij overloop: olie gaat terug naar de lage tank, waardoor hierop niet geschakeld hoeft te worden. De pomp pompt altijd, de olie wordt continu gefiltreerd
ST2: temperature oil in heater tank (130-140).
Moet gekoppeld zijn aan de verwarmingsspiraal.
Lage temperatuur: schakelt in. Temperatuur bereikt: schakelt uit
SP2: electric power heater H2
Moet op temperatuur ST2 geschakeld worden
L3: oil level centrifuge.
Niveau/vulling wordt bepaald door het volume in de hoge tank (visueel?).
SD3: duration centrifugation (10-15s). (variabel)
Mag voor de tests ook wel iets langer.
Een gevoelig product heeft misschien minder omwentelingen nodig en meer tijd.
SR3: De centrifugesnelheid moet dus ingesteld kunnen worden.
SC3: blocking cover closing centrifuge.
Tegen onverwacht sluiten, terwijl iemand er met handen of hoofd tussen komt.
T3: temperature oil in centrifuge.
P4: vacuum in condenser.
Proces cyclus start als het ingestelde vacuüm bereikt is.

De basisvolgorde is:
1. Vacuumpomp P2 staat altijd aan
2. Zorg dat de olie in de voorraadtank T1 op temperatuur is
3. Afsluiters op T1 V1.1 t/m V1.6 moeten gesloten zijn
4. Breng mand met product in de frituur
5. Sluit de vacuum frituur
6. Zorg voor vacuum in de frituur (openen V3.1)
7. Open afsluiter V1.3
8. Na ingestelde vollopen centrifuge met olie V1.3 sluiten en V1.1 openen
9. Centrifugeren starten
10. Na afloop centrifugeertijd: Afsluiter V1.1 sluiten, V3.1 sluiten
11. Vacuum frituur beluchten door V3.1 te sluiten en een beluchtingsafsluiter tussen V3.1 en vacuümfrituur te openen
12. Volledig belucht: centrifugeklep openen
13. Mand mee chips verwijderen
14. Nieuwe mand plaatsen etc.

De vacuumpomp moet los hiervan schakelen op druk. Inschakelen zodra de druk boven 50 of 60 mbar komt (afhankelijk van hoe nauwkeurig dit kan) en uitschakelen zodra de druk beneden 40 mbar komt. Of middels ventiel dat opent bij 40 mbar altijd draaien, maar door dat ventiel nooit te diep gaan.

Not yet modified to new set-up
Using minimal control equipment and as much as possible direct equipment control by design

Starting up:
Oil separation tank
-Valve V1.3 from oil storage/sedimentation tank T1 is closed.
Deze altijd gesloten houden en alleen handmatig openen.
-Valve V2.1 is open.
-Close valve V1.4 to recycle of lower oil storage
-Close valve V2.2 from upper storage to centrifuge
-Close valves V1.1 and V1.2 from centrifuge to lower storage tank

Preheating oil
-Pump P1 oil from lower oil storage to high oil storage
-Electric heater H2 of higher oil storage on for 140 degree Celsius of the oil

vacuum
-open valve V4.1 of Cooler H4 of condensor (using cool water of 5 degree Celsius at the most).
-Water ring pump:
--valve V3.1 to centrifuge is closed
--cold water on V5.2 (< 17 degree Celsius)
--pump P5 on

First time vacuum frying and centrifugation
-open cover C3.1 of centrifuge
-Place basket wih 5 kg of fruit in centrifuge C3
-close cover C3.1 of the centrifuge
-open valve V3.1 of vacuum from pump to centrifuge
=if oil is hot: open valve V2.2 to centrifuge to fill centrifuge (storage in T2 larger then two fillings?)
=close valve V2.2 to centrifuge, if centrifuge filled up to level indicator (automatic?)
-wait 10-15 s to fry the fruit: temperature will decrease to 60 degree Celsius
Centrifuge is turning slowly?
-open valve V1.1
-start centrifuge C3 (during 10-15s?)
-stop centrifuge C3
-close valve V1.1
-close valve V3.1
-open cover C3.1
-take basket out

<u>cycling:</u>
-valves open: V2.1, V4.1, V5.2
-valves closed V1.1, V1.2, V1.3, V1.4, V2.2, V3.1
-pump P1 oil to T2 (can be done directly after release oil by V2.2 and closing V2.2)
-place basket with product through open cover C3.1
-close cover C3.1
-open vacuun valve V3.1
-open valve V2.2 for hot oil to level set.
-using a timer or using ST3 for end temperature
-opening valve V1.1
-centrifugate with timer SD3 (with max)
-close valve V1.1
-close valve V3.1
-open cover C3.1
-take basket out

<u>Stopping:</u>
Cleaning
-recycle vacuum water: V5.1 (to T1)
-sedimentation T1 by V1.3